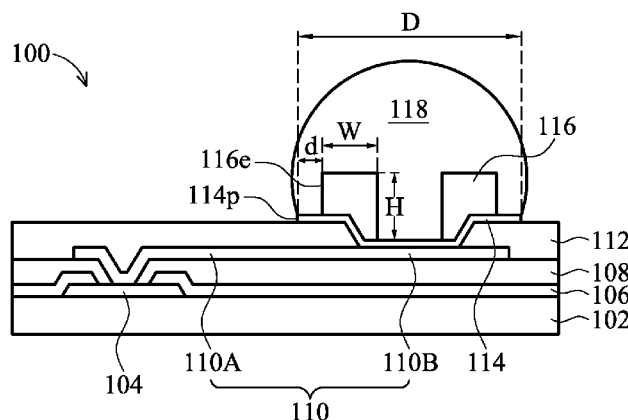


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(45) **Date of Patent:** \*Oct. 18, 2016

- 20 Claims, 4 Drawing Sheets**



(52) **U.S. Cl.**

CPC ..... *H01L 24/10* (2013.01); *H01L 24/11* (2013.01); *H01L 24/16* (2013.01); *H01L 2224/0401* (2013.01); *H01L 2224/05027* (2013.01); *H01L 2224/05111* (2013.01); *H01L 2224/05144* (2013.01); *H01L 2224/05147* (2013.01); *H01L 2224/05155* (2013.01); *H01L 2224/05166* (2013.01); *H01L 2224/05181* (2013.01); *H01L 2224/05186* (2013.01); *H01L 2224/05551* (2013.01); *H01L 2224/05555* (2013.01); *H01L 2224/05572* (2013.01); *H01L 2224/05611* (2013.01); *H01L 2224/05644* (2013.01); *H01L 2224/05647* (2013.01); *H01L 2224/05655* (2013.01); *H01L 2224/05666* (2013.01); *H01L 2224/05681* (2013.01); *H01L 2224/05686* (2013.01); *H01L 2224/10125* (2013.01); *H01L 2224/1146* (2013.01); *H01L 2224/1147* (2013.01); *H01L 2224/11849* (2013.01); *H01L 2224/13012* (2013.01); *H01L 2224/13076* (2013.01); *H01L 2224/13111* (2013.01); *H01L 2224/13113* (2013.01); *H01L 2224/13116* (2013.01); *H01L 2224/13139* (2013.01); *H01L 2224/13144* (2013.01); *H01L 2224/13147* (2013.01); *H01L 2224/13155* (2013.01); *H01L 2224/16237* (2013.01); *H01L 2224/16238* (2013.01); *H01L 2224/81191*

(2013.01); *H01L 2924/00014* (2013.01); *H01L 2924/01029* (2013.01); *H01L 2924/12042* (2013.01)

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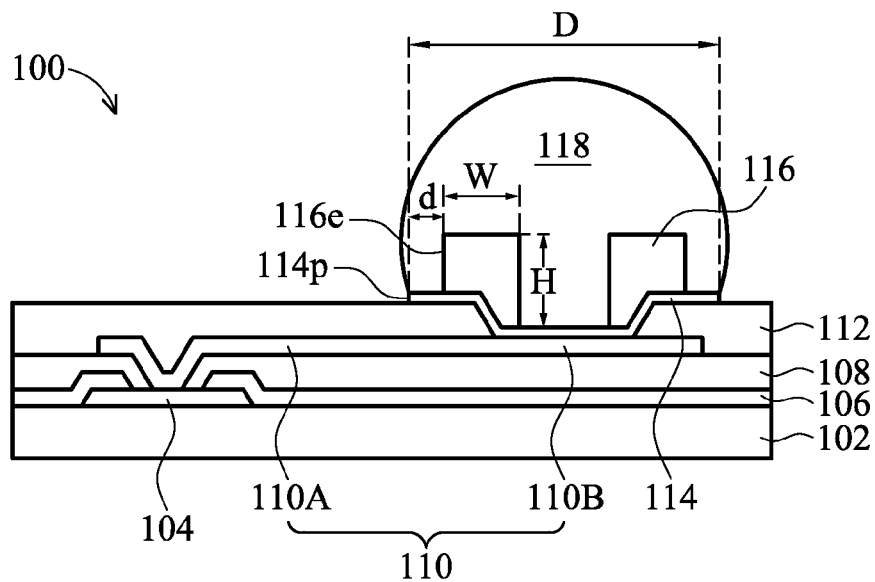


Figure 1

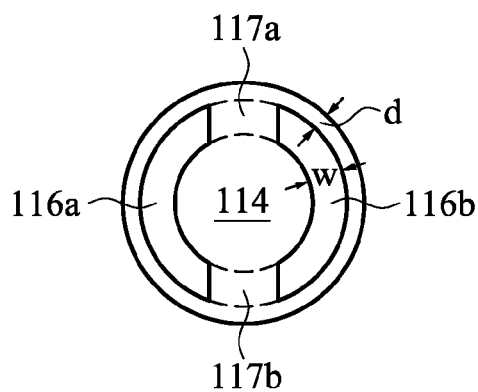


Figure 2

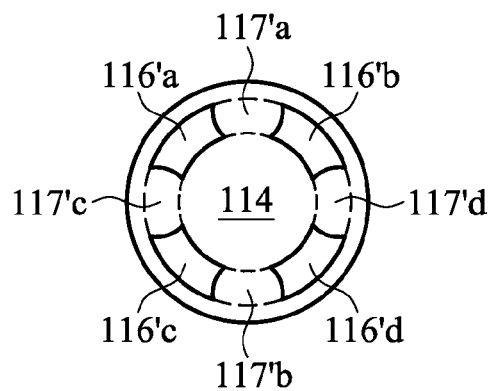


Figure 3

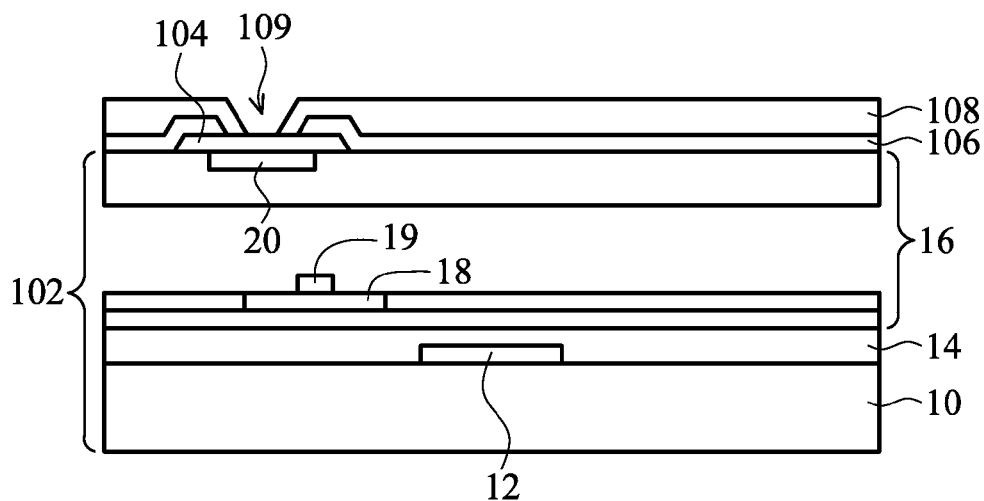


Figure 4

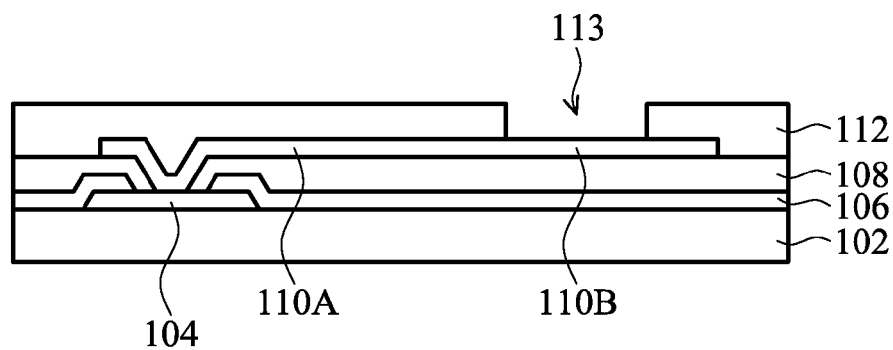


Figure 5

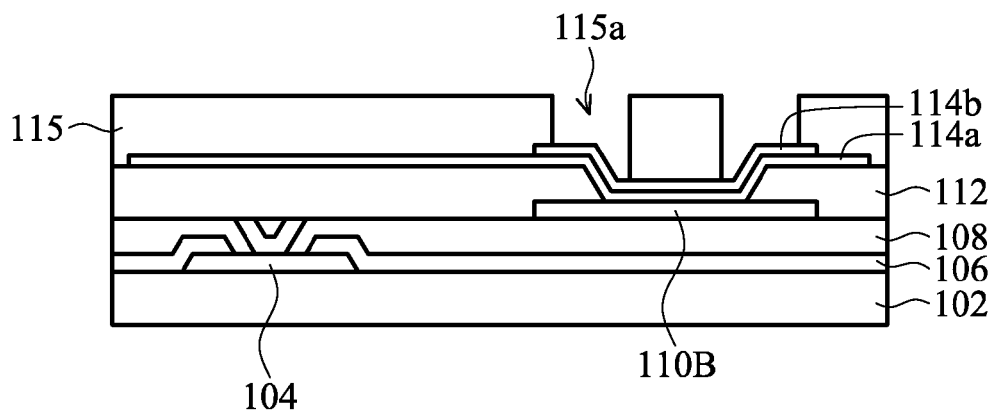


Figure 6

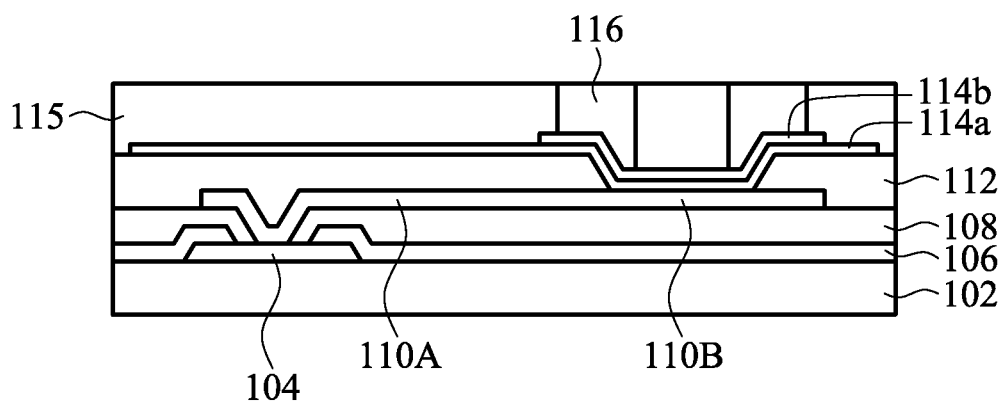


Figure 7

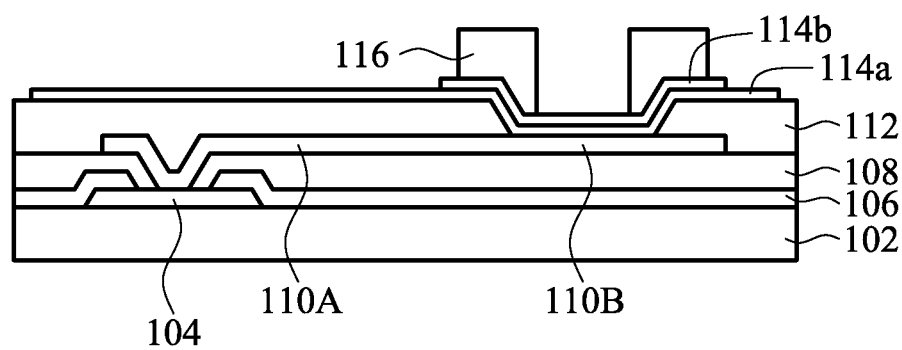


Figure 8

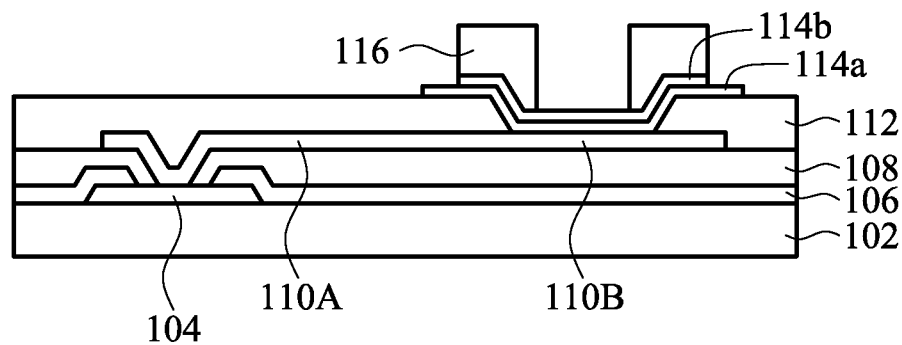


Figure 9

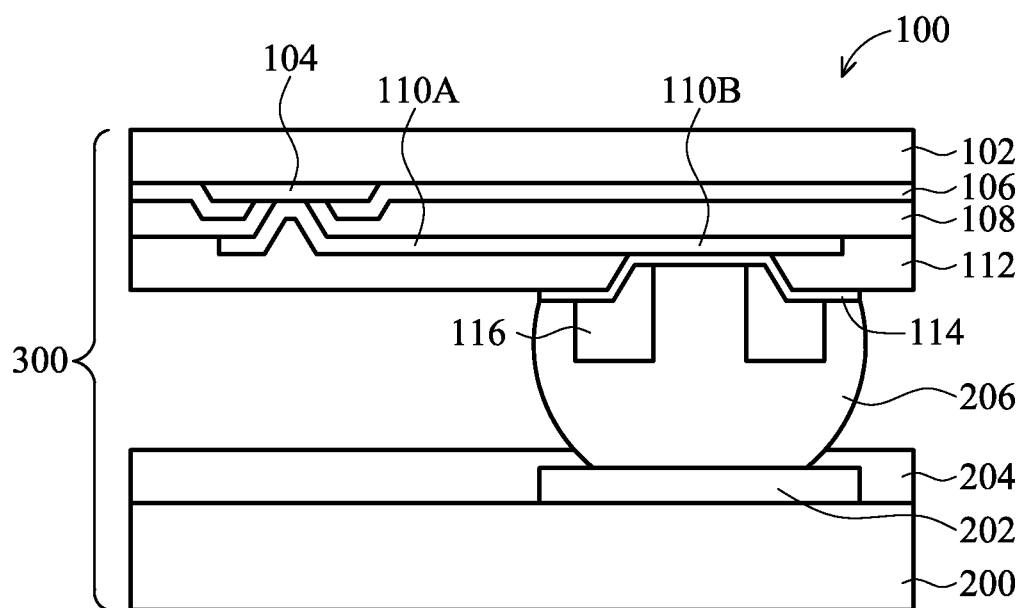


Figure 10

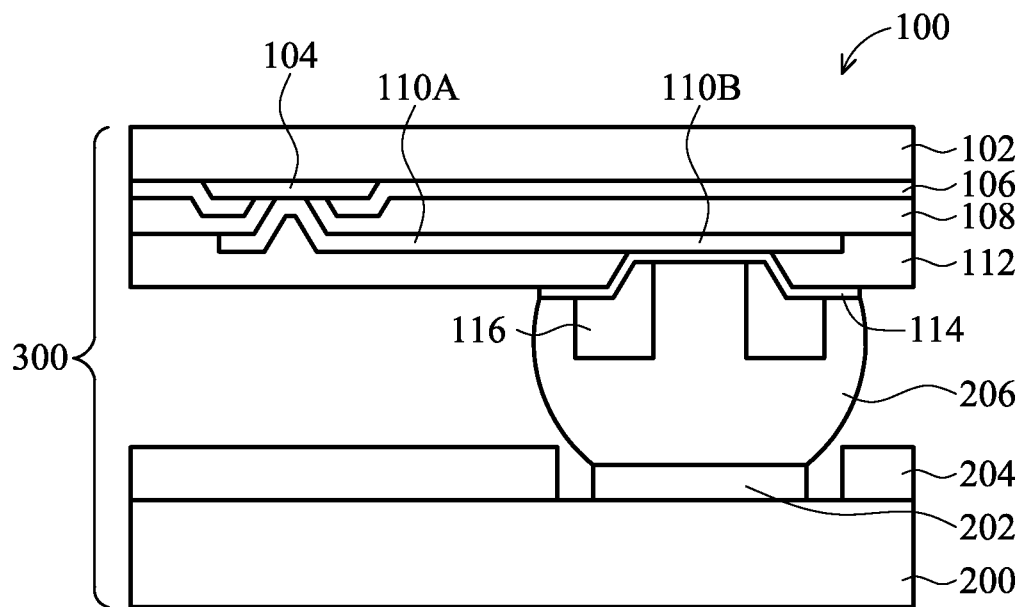


Figure 11

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## COPPER-CONTAINING LAYER ON UNDER-BUMP METALLIZATION LAYER

### PRIORITY CLAIM

The present application is a continuation of U.S. application Ser. No. 13/443,556, filed Apr. 10, 2012, which claims priority of U.S. Provisional Application No. 61/590,261, filed Jan. 24, 2012, which are incorporated herein by reference in their entirety.

### BACKGROUND

Generally, a semiconductor die may be bonded to another substrate, such as an organic printed circuit board, using such technologies as ball grid arrays or controlled collapse chip connection (C4) solder bumps. In one such process, a solder bump may be formed on either the semiconductor die or the substrate or on both using methods such as plating, paste screening or ball mount and then reflowing the solder into a desired bump shape. Once the solder bump has been formed, the contacts on the semiconductor die are aligned with their corresponding contacts on the substrate, with the solder bump located between the contacts. Once aligned, the solder bump is again reflowed and liquefied, wherein the liquefied solder flows and wets onto the contact pads, providing an electrical and physical connection between the semiconductor die and the substrate.

However, a semiconductor die may have a much different coefficient of thermal expansion than the substrate. As such, when the semiconductor die is bonded to the substrate and they are both going through the thermo-mechanical cycling which may be used to simulate the system power on and off cycles to meet the JEDEC reliability test requirements, the semiconductor die and the substrate will expand during heating up cycles and contract during cooling down cycles to different lengths. Such an expansion causes stresses to form at the solder joints interconnecting the semiconductor die and the substrate. This problem is especially prevalent at connections between the semiconductor die and the substrate. In particular, the stresses caused by the mismatch of coefficients of thermal expansion between the semiconductor die and the substrate are so intense that cracks may actually develop in the solder joints interconnecting the semiconductor die and the substrates. These cracks could then propagate through the whole joint and degrade or even destroy the electrical continuity and/or physical connections between the semiconductor die and the substrates. Such destruction may render the parts useless and require a complete refabrication.

### BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of embodiments of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a cross-sectional view illustrating a crack stopper located on a semiconductor die in accordance with an embodiment;

FIG. 2 is a top view illustrating a crack stopper having openings in accordance with an embodiment;

FIG. 3 is a top view illustrating a crack stopper having openings in accordance with another embodiment;

FIGS. 4-9 are cross-sectional views illustrating a method of forming a crack stopper on a semiconductor substrate in accordance with an embodiment;

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FIG. 10 is a cross-sectional view illustrating a semiconductor die with a crack stopper solder jointed to a substrate in accordance with an embodiment; and

FIG. 11 is a cross-sectional view illustrating a semiconductor die with a crack stopper solder jointed to another substrate in accordance with an embodiment.

Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the embodiments and are not necessarily drawn to scale.

### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of embodiments are discussed in detail below. It should be appreciated, however, that the embodiments provide many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the embodiments, and do not limit the scope of the embodiments.

The embodiments will be described with respect to embodiments in a specific context, namely a crack stopper for a solder joint between a semiconductor die and a substrate in a wafer level chip scale package, C4 or package-on-package (PoP) interconnect structures. The embodiments may also be applied, however, to other bonding processes.

With reference now to FIG. 1, there is shown a semiconductor die 100 with a semiconductor base substrate 102, a contact pad 104, a passivation layer 106, a first protective layer 108, a post-passivation interconnect (PPI) layer 110, a second protective layer 112, an under-bump metallization (UBM) layer 114, a crack stopper 116 and a bump 118.

The semiconductor base substrate 102 may comprise bulk silicon, doped or undoped, or an active layer of a silicon-on-insulator (SOI) substrate. Generally, an SOI substrate comprises a layer of a semiconductor material such as silicon, germanium, silicon germanium, SOI, silicon germanium on insulator (SGOI), or combinations thereof. Other substrates that may be used include multi-layered substrates, gradient substrates, or hybrid orientation substrates. Various active devices and/or passive devices may be formed either within or else on the semiconductor base substrate 102. An interconnection structure including metallization layers and inter-metal-dielectric (IMD) layers can be formed on the semiconductor base substrate 102 to connect the various active devices and/or passive devices, resulting in functional circuitry.

The contact pad 104 is formed on the upper-most dielectric layer and connected the upper-most metallization layer of the interconnect structure. The contact pad 104 may comprise aluminum, but other materials, such as copper, may alternatively be used. The passivation layer 106 is formed on the semiconductor base substrate 102 over the interconnection structure and then patterned with an opening to expose a portion of the contact pad 104. The passivation layer 106 may be made of one or more suitable dielectric materials such as silicon oxide, silicon nitride, low-k dielectrics such as carbon doped oxides, extremely low-k dielectrics such as porous carbon doped silicon dioxide, combinations of these, or the like.

The first protective layer 108 is formed on the passivation layer 106 and patterned with another opening to expose a portion of the contact pad 104. The opening through the first protective layer 108 allows for electrical contact between the contact pad 104 and PPI layers 110. The first protective layer

**106** may be made of one or one more suitable polymer materials such as epoxy, polyimide, benzocyclobutene (BCB), polybenzoxazole (PBO), and the like, although other relatively soft, often organic, dielectric materials can also be used. Alternatively, the first protective layer **108** may be formed of a material similar to the material used as the passivation layer **106**, such as silicon oxides, silicon nitrides, low-k dielectrics, extremely low-k dielectrics, combinations of these, and the like.

The PPI layer **110** is a patterned metallization layer on the first protective layer **108** and electrically connected to the contact pad **104** through the opening in the first protective layer **108**. In some embodiments, the PPI layer **110** includes at least one of a copper (Cu) layer, an aluminum (Al) layer, a copper alloy layer, a nickel layer, a gold layer, or other mobile conductive materials. In one embodiment, the PPI layer **110** includes a dielectric layer on the metallization layer, such as a silicon nitride layer, an oxide layer or the like. In some embodiments, the PPI layer **110** functions as power lines, re-distribution lines (RDL), inductors, capacitors or any passive components. In an embodiment, the PPI layer **110** includes an interconnect line region **110A** and a landing pad region **110B**, and a bump feature will be formed over and electrically connected to the landing pad region **110B** in subsequent processes. In an embodiment, the landing region **110B** is not directly over the contact pad **104** as depicted in FIG. 1. In other embodiments, the landing pad region **110B** is directly over the contact pad **104**.

The second protective layer **112** is formed on PPI layer **110** and the exposed surface of the first protective layer **108**. The second protective layer **112** is patterned to form a window to expose a portion of the landing pad region **110B** of the PPI layer **110**. The second protective layer **112** may be made of one or one more suitable polymer materials such as epoxy, polyimide, benzocyclobutene (BCB), polybenzoxazole (PBO), and the like, although other relatively soft, often organic, dielectric materials can also be used. In some embodiments, the second protective layer **112** is formed of a material similar to or the same as the material used as the first protective layer **108**.

The UBM layer **114** is formed on the exposed portion of the landing pad region **110B**. In an embodiment, the UBM layer **114** is formed along the bottom and sidewalls of the window in the second protective layer **112** and extends to the surface of the second protective layer **112** to a predetermined distance. In an embodiment the UBM layer **114** includes at least one conductive layer formed of titanium, titanium, titanium copper, nickel or alloys thereof. Any suitable conductive materials or combination of different layers of material that may be used for the UBM layer **114** are intended to be included within the scope of the current application. The UBM layer **114** may be created by forming each layer over the second protective layer **112** and the window of the second protective layer **112**. The forming of the UBM layer **114** may be performed using a plating process, such as electrochemical plating, although other processes of formation, such as sputtering, evaporation, or PECVD process, may alternatively be used depending upon the desired materials. Once the desired layers have been formed, portions of the UBM layer **114** may then be removed through a suitable photolithographic masking and etching process to remove the undesired material and to leave the UBM layer **114** in a desired shape, such as a circular, octagonal, square, or rectangular shape, although any desired shape may alternatively be formed.

The crack stopper **116** may be formed over and in physical contact with the UBM layer **114**. In some embodiments, the

crack stopper **116** is formed using a masking and plating process in the shapes described with respect to FIGS. 1-3. The crack stopper **116** may be formed from a conductive material such as copper, although other conductive materials such as nickel, gold, or metal alloys, the like or a combination of them constructed in separate layers may also be used.

The crack stopper **116** may be placed and shaped in such a fashion as to extend from the UBM layer **114** and, eventually, into the bump **118**. Additionally, the crack stopper **116** may be placed and shaped in such a fashion as to intercept and stop any cracks that may originate from the edge of the UBM layer **114** and/or PPI layer **110** and prevent the cracks from spreading further into the interior of the UBM layer **114** and/or PPI layer **110**.

FIG. 2 illustrates one such placement and shape of the crack stopper **116**, in which FIG. 2 is a top-down (plan) view of the crack stopper **116** and the UBM layer **114**. In this embodiment the crack stopper **116** may be placed near the outside periphery **114p** of the UBM layer **114** and may be shaped in a hollow cylinder e.g., a ring shape, whose outside edge **116e** runs close to the outside periphery **114p** of the UBM layer **114**. In an embodiment, the diameter (D) of the UBM layer **114** and a distance (d) between the outside edge of the crack stopper **116** and the outside periphery of the UBM layer **114** satisfy the formula:  $\frac{1}{3} * D > 3 \mu\text{m}$ . For example,  $D = 240 \mu\text{m}$  and  $80 \mu\text{m} > d > 3 \mu\text{m}$ . The crack stopper **116** has a wall thickness W and a wall height H. In at least one embodiment, the ratio of height to thickness (H/W) is as follows:  $H/W \geq 1$  or  $H/W \geq 2$ . In some embodiments, the thickness (W) is less than about 20  $\mu\text{m}$ , for example about 15  $\mu\text{m}$ . In some embodiments, the height (H) is greater than 15  $\mu\text{m}$ , or greater than 20  $\mu\text{m}$ , for example, the height is about 30  $\mu\text{m}$ . In addition, the crack stopper **116** may have at least two openings **117a** and **117b** so as to separate the crack stopper **116** into two segments **116a** and **116b**. In an embodiment, the two openings **117a** and **117b** together have a total opening area A in plan view (i.e., as seen in a thickness direction of the substrate **102**), and the two segments **116a** and **116b** together have a total crack stopper area B in plan view. The areas A and B satisfy the formula:  $0.7 * B > A > 0.03 * B$ .

FIG. 3 is a top-down (plan) view of the crack stopper **116** and the UBM layer **114** according to another embodiment. In this embodiment, the crack stopper **116** may be placed near the outside periphery **114p** of the UBM layer **114** and may be shaped in a ring shape, such as a hollow cylinder whose outside edge **116e** runs close to the outside periphery of the UBM layer **114** with a distance (d) in between. In an embodiment, the diameter (D) and the distance (d) satisfy the formula:  $\frac{1}{3} * D > 3 \mu\text{m}$ . In this embodiment, the crack stopper **116** has four openings **117a**, **117b**, **117c** and **117d** so as to separate the crack stopper **116** into four segments **116a**, **116b**, **116c** and **116d**. In an embodiment, the four openings **117a**, **117b**, **117c** and **117d** together have a total opening area A in plan view, and the four segments **116a**, **116b**, **116c** and **116d** together have a total crack stopper area B in plan view. The areas A and B satisfy the formula:  $0.7 * B > A > 0.03 * B$ .

By forming the crack stopper **116** as a hollow cylinder with openings **117** around the outside periphery **114p** of the UBM layer **114**, cracks that may develop along the outside of the UBM layer **114** and/or PPI layer **110** and propagate inwards will encounter the crack stopper **116** perpendicularly. Such a perpendicular interaction will help prevent the crack from propagating any further into the UBM layer **114** and/or PPI layer **110**. In this fashion, the crack stopper **116**

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can prevent cracks from degrading the performance of the semiconductor die **100**. The openings **117** in the hollow cylinder may provide a measure of stress relief. For example, during thermal cycling, when the material of the hollow cylinder is expanding, the openings **117** allow the hollow cylinder to expand without pushing against another part of the hollow cylinder. As such, damage from the stresses caused by this expansion mismatch during the thermo-mechanical cycling may be reduced.

However, as one of ordinary skill in the art will recognize, the above described ring shapes and/or hollow cylinders are intended to be illustrative examples only and are not intended to limit the hollow cylinder. Other shapes that maintain the hollow cylinder but that are not perfectly circle are also fully intended to be included in some embodiments. For example, the outside edge **116e** of the crack stopper **116** may be shaped as an octagon, pentagon, hexagon, and the like, while still maintaining the overall ring shape. The inside edge of the crack stopper **116**, in some embodiments, has a different shape from that of the outside edge of the crack stopper **116**.

Returning now to FIG. 1, after the crack stopper **116** has been formed, the bump **118** is formed on the UBM Layer **114** to cover the crack stopper **116**. In one embodiment, the bump **118** is a solder bump formed by attaching a solder ball on the UBM layer **114** and then thermally reflowing the solder material. In some embodiments, the solder bump may include a lead-free pre-solder layer, SnAg, or a solder material including alloys of tin, lead, silver, copper, nickel, bismuth, or combinations thereof. In some embodiments, the solder bump may be formed by plating a solder layer with photolithography technologies followed by reflowing processes. In some embodiments, the bump **118** has a diameter of about 200  $\mu\text{m}$  to about 300  $\mu\text{m}$ . In other embodiments, the bump **118** has a diameter of about 100  $\mu\text{m}$  to about 200  $\mu\text{m}$ . In still other embodiments, the bump **118** has a diameter of less than about 100  $\mu\text{m}$ . By placing the crack stopper **116** on the UBM layer **114**, the crack stopper **116** may prevent the propagation of cracks that may form within the bump **118**. The crack stopper can provide better solder wetting solder jointing results, and prevent voids inside the solder joint structure as well.

FIGS. 4-9 illustrate various intermediate stages of a method of forming a crack stopper on a semiconductor die in accordance with an embodiment shown in FIG. 1.

Referring first to FIG. 4, the semiconductor substrate **102** includes a substrate **10**, an electrical circuitry **12**, an inter-layer dielectric (ILD) layer **14**, inter-metal dielectric (IMD) layers **16** and the associated metallization layers.

A portion of the substrate **10** having electrical circuitry formed thereon is shown, in accordance with an embodiment. The substrate **10** may comprise, for example, bulk silicon, doped or undoped, or an active layer of a semiconductor-on-insulator (SOI) substrate. The substrate **10** may be provided as a wafer level scale or a chip level scale. Other substrates, such as a multi-layered or gradient substrate may also be used.

Electrical circuitry **12** formed on the substrate **10** may be any type of circuitry suitable for a particular application. In an embodiment, the electrical circuitry **12** includes electrical devices formed on the substrate **10** with one or more dielectric layers overlying the electrical devices. Metal layers may be formed between dielectric layers to route electrical signals between the electrical devices. Electrical devices may also be formed in one or more dielectric layers. For example, the electrical circuitry **12** may include various N-type metal-oxide semiconductor (NMOS) and/or P-type

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metal-oxide semiconductor (PMOS) devices, such as transistors, capacitors, resistors, diodes, photo-diodes, fuses, and the like, interconnected to perform one or more functions. The functions may include memory structures, processing structures, sensors, amplifiers, power distribution, input/output circuitry, or the like. One of ordinary skill in the art will appreciate that the above examples are provided for illustrative purposes only to further explain applications of some illustrative embodiments and are not meant to limit the disclosure in any manner. Other circuitry may be used as appropriate for a given application.

The ILD layer **14** may be formed, for example, of a low-K dielectric material, such as phosphosilicate glass (PSG), borophosphosilicate glass (BPSG), fluorinated silicate glass (FSG),  $\text{SiO}_x\text{C}_y$ , Spin-On-Glass, Spin-On-Polymers, silicon carbon material, compounds thereof, composites thereof, combinations thereof, or the like, by any suitable method, such as spinning, chemical vapor deposition (CVD), and/or plasma-enhanced CVD (PECVD). In some embodiments, the ILD layer **14** may comprise a plurality of dielectric layers. Contacts (not shown) may be formed through the ILD layer **14** to provide an electrical contact to the electrical circuitry **12**.

One or more inter-metal dielectric (IMD) layers **16** and the associated metallization layers are formed over the ILD layer **14**. Generally, the one or more IMD layers **16** and the associated metallization layers (such as metal lines **18** and vias **19**) are used to interconnect the electrical circuitry **12** to each other and to provide an external electrical connection. The IMD layers **16** may be formed of a low-K dielectric material, such as FSG formed by PECVD techniques or high-density plasma CVD (HDPCVD), or the like, and may include intermediate etch stop layers. In some embodiments, one or more etch stop layers (not shown) may be positioned between adjacent ones of the dielectric layers, e.g., the ILD layer **14** and the IMD layers **16**. Generally, the etch stop layers provide a mechanism to stop an etching process when forming vias and/or contacts. The etch stop layers are formed of a dielectric material having a different etch selectivity from adjacent layers, e.g., the underlying semiconductor substrate **10**, the overlying ILD layer **14**, and the overlying IMD layers **16**. In an embodiment, etch stop layers may be formed of SiN, SiCN, SiCO, CN, combinations thereof, or the like, deposited by CVD or PECVD techniques.

In some embodiments, the metallization layers including metal lines **18** and vias **19** may be formed of copper or copper alloys, or of other metals. Further, the metallization layers include a top metal layer **20** formed and patterned in or on the uppermost IMD layer to provide external electrical connections and to protect the underlying layers from various environmental contaminants. In some embodiments, the uppermost IMD layer may be formed of a dielectric material, such as silicon nitride, silicon oxide, undoped silicon glass, and the like. In subsequent drawings, semiconductor substrate **10**, electrical circuitry **12**, ILD layer **14**, and metallization layers **18** and **19** are not illustrated. In some embodiments, the top metal layer **20** is formed as a part of the top metallization layer on the uppermost IMD layer.

Thereafter, the contact pad **104** is formed and patterned to contact the top metal layer **20**, or alternatively, electrically coupled to top metal layer **20** through a via. In some embodiments, the contact pad **104** may be formed of aluminum, aluminum copper, aluminum alloys, copper, copper alloys, or the like. One or more passivation layers, such as a passivation layer **106** are formed and patterned over the contact pads **104**. In some embodiments, the passivation

layer **106** may be formed of a dielectric material, such as undoped silicate glass (USG), silicon nitride, silicon oxide, silicon oxynitride or a non-porous material by any suitable method, such as CVD, PVD, or the like. The passivation layer **106** is formed to cover the peripheral portion of the contact pad **104**, and to expose the central portion of contact pad **104** through the opening in passivation layer **106**. The passivation layer **106** may be a single layer or a laminated layer. In FIG. 4, a single layer of contact pad and a passivation layer are shown for illustrative purposes only. As such, other embodiments may include any number of conductive layers and/or passivation layers.

Next, a first protective layer **108** is formed and patterned over the passivation layer **106**. In some embodiments, the first protective layer **108** may be, for example, a polymer layer, which is patterned to form an opening **109**, through which the contact pad **104** is exposed. In some embodiments, the polymer layer may be formed of a polymer material such as an epoxy, polyimide, benzocyclobutene (BCB), polybenzoxazole (PBO), and the like, although other relatively soft, often organic, dielectric materials can also be used. The formation methods include spin coating or other methods. The first protective layer **108** has a thickness in a range between about 1  $\mu\text{m}$  and about 10  $\mu\text{m}$ . For example, a thickness between about 5  $\mu\text{m}$  and about 8  $\mu\text{m}$ .

Referring to FIG. 5 at least one metallization layer **110** is formed on the first protective layer **108** and fills the opening **109** and then patterned as an interconnect layer **110**, which is electrically connected to the contact pad **104** and may expose a portion of the underlying first protective layer **108**. In at least an embodiment, the interconnect layer **110** is a post-passivation interconnect (PPI) layer **110**, which may also function as power lines, re-distribution lines (RDL), inductors, capacitors or any passive components. The PPI layer **110** includes an interconnect line region **110A** and a landing pad region **110B**. In some embodiments, the interconnect line region **110A** and the landing pad region **110B** may be formed simultaneously, and may be formed of a same conductive material. A bump feature will be formed over and electrically connected to the landing pad region **110B** in subsequent processes. In some embodiments, the PPI layer **110** may include copper, aluminum, copper alloy, or other mobile conductive materials using plating, electroless plating, sputtering, chemical vapor deposition methods, and the like. In one embodiment, the PPI layer **110** includes a copper layer or a copper alloy layer. In the embodiment of FIG. 5, the landing region **110B** is not directly over the contact pad **104**. In other embodiments, through the routing of PPI layer **110**, the landing pad region **110B** is directly over the contact pad **104**.

With reference to FIG. 5, a second protective layer **112** is then formed on the substrate **10** to cover the PPI layer **110**. Using photolithography and/or etching processes, the second protective layer **112** is further patterned to form an opening **113** exposing at least a portion of the landing pad region **110B** of the PPI layer **110**. The formation methods of the opening **113** may include lithography, wet or dry etching, laser drill, and/or the like. In some embodiments, the second protective layer **112** is formed of a polymer layer, such as an epoxy, polyimide, benzocyclobutene (BCB), polybenzoxazole (PBO), and the like, although other relatively soft, often organic, dielectric materials may also be used. In some embodiments, the second protective layer **112** is formed of a non-organic material selected from un-doped silicate glass (USG), silicon nitride, silicon oxynitride, silicon oxide, and combinations thereof.

As shown in FIG. 6, a first UBM layer **114a** is formed on the entire surface to cover the second protective layer **112** and the exposed portion of the landing pad region **110B** so as to be electrically connected to the PPI layer **110**. Then a second UBM layer **114b** is formed and patterned on the first UBM layer **114a**, resulting in a patterned UBM layer **114b** over the landing pad region **110B**, on which the crack stopper **116** will be formed. A photoresist layer **115** is then formed on the UBM layers **114a** and **114b** and patterned with an opening **115a** to expose a portion of the second UBM layer **114b**. The shape, dimension and location of the opening **115a** are corresponding to those of the crack stopper **116**, respectively. The UBM layers **114a** and **114b** are formed by using metal deposition methods. In some embodiments, the UBM layers **114a** and **114b** include at least one metallization layer comprising titanium (Ti), tantalum (Ta), titanium nitride (TiN), tantalum nitride (Ta<sub>2</sub>N), copper (Cu), copper alloys, nickel (Ni), tin (Sn), gold (Au), or combinations thereof. In one embodiment, the first UBM layer **114a** includes at least one Ti-containing layer and the second UBM layer **114b** includes at least one Cu-containing layer.

As shown in FIG. 7, a conductive material is formed to fill the opening **115a** of the photoresist layer **115** and to be electrically connected to the UBM layer **114**. After removing the photoresist layer **115**, the conductive material layer left on the UBM layer **114b** forms the crack stopper **116** as depicted in FIG. 8. In at least one embodiment, the crack stopper **116** includes a Cu layer. The Cu layer comprises pure elemental copper, copper containing unavoidable impurities, and/or copper alloys containing minor amounts of elements such as Ta, indium (In), Sn, zinc (Zn), manganese (Mn), Cr, Ti, germanium (Ge), strontium (Sr), platinum (Pt), magnesium (Mg), aluminum (Al) or zirconium (Zr). The crack stopper **116** may be formed by sputtering, printing, electroplating, electro-less plating, electrochemical deposition (ECD), molecular beam epitaxy (MBE), atomic layer deposition (ALD), and/or commonly used CVD methods. In one embodiment, the Cu layer is formed by electrochemical plating (ECP).

Then as shown in FIG. 9, the exposed surface of the first UBM layer **114a** are etched, leaving the crack stopper **116** standing on the UBM layer **114**. In some embodiments, the UBM etching process may use wet etching or dry etching process. The second UBM layer **114b** may be etched during the UBM etching process, and therefore the periphery of the second UBM layer **114b** may be substantially aligned with the outside edge of the crack stopper **116**.

Thereafter the bump **118** is formed on the UBM layer **114** to cover the crack stopper **116** as described and depicted in FIG. 1. The bump **118** can be a solder bump, a Cu bump or a metal bump including Ni or Au. In one embodiment, the bump **118** is a solder bump formed by attaching a solder ball on the UBM layer **114** and then thermally reflowing the solder material. In some embodiments, the solder bump may include a lead-free pre-solder layer, SnAg, or a solder material including alloys of tin, lead, silver, copper, nickel, bismuth, or combinations thereof. In some embodiments, the solder bump may be formed by plating a solder layer with photolithography technologies followed by reflowing processes.

After the bump formation, for example, an encapsulant may be formed, a singulation process may be performed to singulate individual dies **100**, and wafer-level or die-level stacking or the like may be performed. It should be noted, however, that embodiments may be used in many different situations. For example, embodiments may be used in a die-to-die bonding configuration, a die-to-wafer bonding

configuration, a wafer-to-wafer bonding configuration, die-level packaging, wafer-level packaging, or the like.

FIG. 10 is a cross-sectional diagram depicting an exemplary embodiment of a flip-chip assembly. The semiconductor die 100 shown in FIG. 1 is flipped upside down and attached to another substrate 200 at the bottom of FIG. 10. In some embodiments, the substrate 200 may be a package substrate, board (e.g., a printed circuit board (PCB)), a wafer, a die, an interposer substrate, or other suitable substrate. The bump structure is coupled to the substrate 200 through various conductive attachment points. For example, a conductive region 202 is formed and patterned on the substrate 200. The conductive region 202 is a contact pad or a portion of a conductive trace, which is presented and defined by a mask layer 204. In one embodiment, the mask layer 204 is a solder resist layer formed and patterned on the substrate 200 to expose the conductive region 202. The mask layer 204 has a mask opening, which provides a window for solder joint formation. For example, a solder layer including alloys of tin, lead, silver, copper, nickel, bismuth, or combinations thereof may be provided on the conductive region 202. In some embodiments, the semiconductor die 100 can be coupled to the substrate 200 to form a joint structure 206 between the landing pad region 110B and the conductive region 202. In an embodiment, the joint structure 206 is a solder joint structure. By providing the crack stopper 116 in the bump 118, the crack stopper 116 is also embedded in the solder joint structure 206 after the assembly process to provide a better joint scheme and void-less joint structure, thus achieving solder jointing quality and increasing thermal fatigue life in the packaging assembly. For example, a solder joint structure can be formed by a coupling process includes a flux application, chip placement, reflowing of melting solder joints, and/or cleaning of flux residue. The semiconductor die 100, the joint structure 206, and the substrate 200 may be referred to as a packaging assembly 300, or in the present embodiment, a flip-chip packaging assembly.

In alternative embodiments, the semiconductor die 100 can be flipped upside down and attached to another substrate 400 with non-solder mask defined technology as depicted in FIG. 11. The conductive region 202 is a contact pad or a portion of a conductive trace, which is not defined by a mask layer 204.

An aspect of this description is related to a semiconductor device. The semiconductor device comprises an under-bump metallization (UBM) layer over a substrate. The semiconductor device also comprises a copper-containing layer having a base portion over the UBM layer. The semiconductor device further comprises a solder bump over the UBM layer and over the copper-containing layer. The base portion is embedded in the solder bump. The copper-containing layer has a cylindrical shape and comprises at least two segments separated by at least two openings. A first total area (A) of the at least two openings is greater than about 3% of a second total area (B) of the at least two segments. The first total area (A) is less than about 70% of the second total area (B) of the at least two segments.

Another aspect of this description is related to an assembly. The assembly comprises a semiconductor die. The semiconductor die comprises a first substrate, an under-bump metallization (UBM) layer over the first substrate, and a cylindrical-shaped metal-containing layer over the UBM layer. The metal-containing layer is located along and within an outside periphery of the UBM layer. The assembly also comprises a second substrate. The assembly further comprises a solder joint structure coupling the semiconductor die to the second substrate. The metal-containing layer has at

least two segments separated by at least two openings. A first total area (A) of the at least two openings and a second total area (B) of the at least two segments satisfy the following equation:  $0.7 \cdot B > A > 0.03 \cdot B$ .

A further aspect of this description is related to a semiconductor device. The semiconductor device comprises an under-bump metallization (UBM) layer over a semiconductor substrate. The UBM layer comprises a first layer and a second layer. The semiconductor device also comprises a copper-containing layer having a base portion and at least two segments separated by at least two openings over the UBM layer. The copper-containing layer is located along an exterior region of the UBM layer, within an outside periphery of the first layer, and aligned with an outside periphery of the second layer. The semiconductor device further comprises a conductive material over the UBM layer and the copper-containing layer. The base portion is embedded in the conductive material. The copper-containing layer is a hollow cylinder. A first total area (A) of the at least two openings and a second total area (B) of the at least two segments satisfy the following equation:  $0.7 \cdot B > A > 0.03 \cdot B$ .

Although the embodiments and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the embodiments as defined by the appended claims. For example, the materials and methods of formation of the crack stoppers may be modified while remaining within the scope of the embodiments. Additionally, the precise shape of the crack stoppers may be adjusted in order to help prevent or reduce the propagation of cracks.

Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the embodiments, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the embodiments. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A semiconductor device, comprising:

an under-bump metallization (UBM) layer over a substrate;

a copper-containing layer having a base portion over the UBM layer; and

a solder bump over the UBM layer and over the copper-containing layer, the base portion being embedded in the solder bump;

wherein

the copper-containing layer has a cylindrical shape and comprises at least two segments separated by at least two openings,

a first total area (A) of the at least two openings is greater than about 3% of a second total area (B) of the at least two segments, and

the first total area (A) is less than about 70% of the second total area (B) of the at least two segments.

2. The semiconductor device of claim 1, wherein the copper-containing layer has a thickness (W), a height (H), and a H/W ratio greater than or equal to 1.0.

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3. The semiconductor device of claim 2, wherein the H/W ratio is equal to or greater than 2.0.

4. The semiconductor device of claim 1, wherein the copper-containing layer comprises at least four segments separated by at least four openings.

5. The semiconductor device of claim 1, wherein a distance (d) between an outside edge of the copper-containing layer and the outside periphery of the UBM layer is greater than about 3.0 micrometers.

6. The semiconductor device of claim 5, wherein the distance (d) is greater than about  $\frac{1}{3}$  of a diameter (D) of the UBM layer.

7. The semiconductor device of claim 1, further comprising:

- an interconnect layer under the UBM layer; and
- a passivation layer under the interconnect layer.

8. The semiconductor device of claim 7, further comprising:

- a polymer layer, wherein a portion of the polymer layer is between the interconnect layer and the UBM layer.

9. An assembly, comprising:

a semiconductor die, comprising:

- a first substrate;
- an under-bump metallization (UBM) layer over the first substrate; and
- a cylindrical-shaped metal-containing layer over the UBM layer, the metal-containing layer being located along and within an outside periphery of the UBM layer;

a second substrate; and

a solder joint structure coupling the semiconductor die to the second substrate, wherein

the metal-containing layer has at least two segments separated by at least two openings, and

a first total area (A) of the at least two openings and a second total area (B) of the at least two segments satisfy the following equation:  $0.7*B > A > 0.03*B$ .

10. The assembly of claim 9, wherein the metal-containing layer has a height (H), a width (W), and a H/W ratio of at least 1.0.

11. The assembly of claim 10, wherein the H/W ratio is equal to or greater than 2.0.

12. The assembly of claim 9, wherein the metal-containing layer has a height (H) greater than about 15.0 micrometers.

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13. The assembly of claim 9, wherein a distance (d) between an outside edge of the metal-containing layer and the outside periphery of the UBM layer is greater than about 3.0 micrometers.

14. The assembly of claim 13, wherein a diameter (D) of the UBM layer and the distance (d) satisfy the equation:  $\frac{1}{3}*D > d > 3.0$  micrometers.

15. The assembly of claim 9, wherein the metal-containing layer is in the solder joint structure.

16. The assembly of claim 9, wherein the semiconductor die further comprises:

- an interconnect layer under the UBM layer; and
- a passivation layer under the interconnect layer.

17. The assembly of claim 16, wherein the semiconductor die further comprises:

- a polymer layer, wherein a portion of the polymer layer is between the interconnect layer and the UBM layer, and a portion of the UBM layer is in contact with the interconnect layer.

18. A semiconductor device, comprising:

an under-bump metallization (UBM) layer over a semiconductor substrate, the UBM layer comprising a first layer and a second layer;

a copper-containing layer having a base portion and at least two segments separated by at least two openings over the UBM layer, the copper-containing layer being located along an exterior region of the UBM layer, within an outside periphery of the first layer, and aligned with an outside periphery of the second layer; and

a conductive material over the UBM layer and the copper-containing layer, the base portion being embedded in the conductive material,

wherein

the copper-containing layer is a hollow cylinder, and a first total area (A) of the at least two openings and a second total area (B) of the at least two segments satisfy the following equation:  $0.7*B > A > 0.03*B$ .

19. The semiconductor device of claim 18, further comprising:

- an interconnect layer under the UBM layer; and
- a passivation layer under the interconnect layer.

20. The semiconductor device of claim 19, further comprising:

- a polymer layer over the interconnect layer.

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